Morrison Hershfield Limited
Consulting Engineers

EXAMINATION OF ALTERNATIVE FOUNDATION DESIGNS FOR REMOTE WIND/DIESEL SYSTEMS

Submitted to:

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40 years of innovations that work!

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1. INTRODUCTION

1.1 Authority

This study on foundation systems for wind turbines is presented in accordance with the Agreement between Morrison Hershfield Limited (MH) and Howden Group Canada Ltd. as part of a submission to the Ministry of Energy, Mines and Resources.

1.2 Load Conditions

The wind turbine considered in this report is the Howden HWP60 wind turbine generator. Information on this turbine is given in Appendix A.

For design purposes, the wind load considered acting on the unit corresponds to a maximum steady wind speed of 58 m/s at a height of 20 m. This is the survival wind speed specified in CSA Standard F416-M1985 Small Wind Energy Conversion Systems (SWECS) - Safety, Design, and Operation Criteria. No additional gust factor is required with the survival wind. Ice on the shaft is not considered, as the governing load combination is full wind plus dead load. On that basis the unfactored design loads on the foundation are:

Dead Load	= 73.0 kN
Horizontal Load	= 95.8 kN
Overturning Moment	= 1508.0 kN.m (at base of shaft)

The horizontal load and overturning moment must be considered as potentially being applied in any direction.

1.3 Variables

There are three main variables to be considered in deciding on the appropriate foundation design for a wind turbine at a specific site. These are:

a) The soil conditions, which can vary from muskeg to sound rock.

b) The frost conditions, i.e. seasonal or permafrost.

c) The availability of materials and skilled labour.

Each of these will be discussed individually in Sections 2, 3 and 4.

2. SOIL CONDITIONS

2.1 General

A great variety of soil types may be found over the vast area which is Canada's North. For ease of consideration these have been considered under six main headings.

a) Muskeg
b) Weak cohesive soils
c) Stiff cohesive soils
d) Granular soils
e) Weathered rock
f) Sound rock

A further consideration in dealing with soil is the amount of water present. Is soil in a dry, saturated, or submerged state?

2.2 Muskeg

Muskeg is defined as organic terrain, i.e. "A tract of country comprising a surficial layer of living vegetation and a sublayer of peat or detritus of any depth, existing in association with various hydrological conditions and underlying mineral formations" (Muskeg Engineering Handbook, University of Toronto Press).

Muskeg is very compressible and is generally not suitable for supporting foundation loads. Therefore, for the purposes of this study it was decided that a wind turbine would not be located at a site where the muskeg is more than 2 metres deep over relatively sound material. Sites with greater depths of muskeg are considered unsuitable, unless the material is permanently frozen.

For sites with overlying muskeg less than 2 metres deep, it is necessary to transfer the foundation loads through the muskeg to the bearing strata

underneath. This can be done by removing the muskeg and substituting more acceptable material, e.g. granular fill, and using a standard mat or grillage foundation. It can also be done by using piles or screw anchors through the muskeg into the bearing material, or into permanently frozen layers of muskeg below.

2.3 Weak Cohesive Soils

Weak cohesive soils are considered to have safe bearing capacity in the range of 50 to 100 kPa. Due to the low bearing capacity of the soil, shallow foundations must be capable of spreading the loads over a large area. Cohesive soils with allowable bearing pressures of less than 50 kPa are not considered in this study.

2.4 Stiff Cohesive Soil

Stiff cohesive soil, provided that it is not associated with a high water table, is a good foundation material. Safe bearing capacities will generally range from 100 to 600 kPa. Most types of foundations are feasible in soil of this type.

Long-term settlement under sustained loading is usually a concern in any cohesive soil. However, since the wind turbine structures are relatively light and the soil pressures from wind loading are of short duration, long-term settlement is not critical.

2.5 Granular Soil

Granular soil can have a wide range of densities and bearing capacities. However, typically the safe bearing capacities range from 100 to 600 kPa. Most types of foundations are therefore feasible. Sites having loose sands with bearing strengths of less than 100 kPa are considered to be not suitable for wind turbine structures because settlements may occur due to vibrations from the operating equipment.

2.6 Weathered Rock

Severely weathered rock may require to be treated like granular material, provided excavation equipment is available to handle it. Where weathering is less severe rock anchors set deeply enough to engage a cone of rock to act as a gravity foundation may be used.

2.7 Sound Rock

On sound rock a levelling base, tied down by rock anchors to prevent overturning, may be used.

2.8 Water Table Level

For all soils, including rock, the level of the water table is important. It affects construction procedures, as dewatering is necessary to work below the water table, and it affects the design, as the submerged unit weight of the material must be used in calculating the weight available to resist overturning. Also in cohesive soils the moisture content affects the cohesion available.

3. FROST CONDITIONS

3.1 General

The proposed use of the wind turbines is in remote areas. Much of the remote area of Canada lies within the regions of either discontinuous or continuous permafrost. Chart II from Climate Information for Building Design in Canada, Supplement No 1 to the National Building Code of Canada, is shown in Appendix B. This shows the permafrost regions. The region south of the discontinuous permafrost limit is subject to seasonal freezing, to a depth varying from 1 to 3 metres.

3.2 Seasonal Freezing

In the region subject to seasonal freezing the primary problem is the movement, particularly non-uniform movement, of the foundation. In frost susceptible soils, where frost heaving can occur, this requires that the foundation be carried down to below the frost level or that the subsoil be protected against freezing. As the foundation itself may form a heat bridge it is necessary to ensure that freezing does not occur under the foundation, by means of added insulation or otherwise. Also in frost susceptible soils the effect of adfreezing to the portion of the foundation which passes through the frost zone, with the potential for uplift forces developing, must be considered.

3.3 Discontinuous Permafrost

In the discontinuous permafrost region several questions must be considered. If the site is not actually in an area of permafrost, then the foundation may be treated as for seasonal freezing. If the site has permafrost, but not to a great depth, it must be considered whether the construction activity will change local conditions so as to change the regime. In that case the permafrost may thaw out over a period with potentially drastic changes in the foundation conditions. Thus it may be necessary to either penetrate through the permafrost to an underlying bearing layer, or, if the foundation is established on the permafrost, to take measures to ensure that thawing of the permafrost layer does not occur.

3.4 Continuous Permafrost

Where the permafrost is continuous, it is necessary to use it as the foundation material. In this instance it is necessary to consider the active zone, i.e. the depth to which thawing of the surface occurs in summer. The foundation loads must be transferred below the active zone, and, as in the seasonal frost zone, precautions must be taken against uplift caused by adfreezing as the active zone refreezes.

As in the discontinuous region, precautions must also be taken against changing the regime to prevent thawing of the permafrost under the foundation. As the wind turbine is unheated this is less of a problem than with a heated building, but care is still required to ensure that the insulation afforded is the same as that provided by the natural conditions prior to installation of the foundation.

4. INSTALLATION PROCEDURES

4.1 Material

As the sites for the wind turbine generators are by definition remote, it is necessary to consider the logistics of moving the foundation materials to the site. In all cases a considerable distance of travel is required from the supply base. For this study it has been considered that no all weather road or rail access is available, so that transportation of materials is by ship or barge during the summer season, and/or by motor vehicles over winter roads.

On that basis the maximum weight of individual components has been restricted to approximately 150 kg (330 lb.), and the maximum length to approximately 7.0 m (23 ft.). Consideration has been given to minimizing the total weight of material transported to keep down transportation costs, which are a large portion of the overall cost.

Where alternatives are feasible the availability of local material must also be considered, such as the availability and suitability of local aggregate for making concrete.

4.2 Equipment

In most remote areas heavy construction equipment is not available. For that reason driven piles have not been considered as an option. At most locations, however, some form of light earth moving equipment is available, so excavation is acceptable. Also most equipment has power take-off available, so the use of drilled piles or screw anchors is considered acceptable. Concrete may be mixed in small batches. For rock sites the use of power drills will be required.

4.3 Skilled Labour

For foundation installation it is considered that the skills available are limited to rough carpentry, mixing of concrete or grout, bolting connections, and operating of available equipment.

5. FOUNDATION TYPES

5.1 General

For a wind turbine generator the foundation must resist vertical downward load (dead load), horizontal load, and overturning moment. In general the combined dead load and overturning moment cause the maximum pressure on the soil. A downward acting component is required to provide the resisting moment. The various types of foundations considered are described below. The drawings for the preliminary designs are presented in Appendix C.

5.2 Shallow Concrete Footing

This is the conventional type of foundation which would normally be considered the first choice in a non-remote area. Typically the footing is founded below frost level, and is buried so as to use the weight of the soil cover in addition to its self-weight to resist overturning. In this study, the footing depths were kept to a minimum to avoid deep excavation and excavation below the water table if possible. In many cases the footings will require insulation around and below the foundation to prevent frost penetration below the base. The thickness and extent of insulation should be determined for each particular site.

The three concrete mat designs presented on Drawings 187-0601-F1, F2 and F3 cover soil conditions ranging from weak cohesive soil with the water table near the ground surface, to dry granular soil or weathered rock. They are relatively easy to construct, require limited excavation, and provide a simple and direct anchorage for the wind turbine base. However, concrete aggregates must be available reasonably economically for this type of footing.

The designs can be used in a permafrost area provided special precautions are taken to prevent degradation of the frozen soil. By placing insulation around and under the footing, and also possibly burying the mat within a raised gravel pad, the active layer can be raised so that the original permafrost is retained in its frozen state.

5.3 Steel Grillage

The steel grillage shown on Drawing No. 187-0601-F4 acts to distribute downward load to the soil in a manner similar to the concrete footing, but relies almost totally on the weight of the soil above it to resist uplift and overturning. In this application, the high overturning forces, along with the 150 kg component weight restriction cause the grillage to be composed of many relatively small beams buried fairly deeply below grade. It was designed for a 100 kPa granular soil with water table below the grillage, but could also be used with weaker cohesive soils if the design is modified.

A major difficulty with the steel grillage is its connection to the wind turbine base. In the drawings for the Howden HWP60 wind turbine provided in Appendix A, the base of the structure is shown anchored to the foundation with 15-M36 anchor bolts evenly spaced in a circular arrangement. It was not possible to connect the circular 15 bolt arrangement directly to the foundation's square grid of steel wide flange members. Therefore, a connection system was designed which consists of a transfer ring and four transfer beams. The transfer ring changes the bolting arrangement from 15 to 16 evenly spaced bolts, while the transfer beams change the bolting pattern from circular to square. Note that a wind turbine base designed with 16 rather than 15 anchor bolts would simplify the connection by eliminating the transfer ring component. Alternatively, with further design, the functions of transfer ring and transfer beams could be combined in a single component.

The steel grillage requires some form of corrosion protection, such as galvanizing, since it is permanently exposed to soil. It also requires a significant number of bolts, which also must be galvanized.

The grillage is not recommended for use in permafrost regions for two reasons. First, it requires relatively deep excavation, which would probably disturb the permafrost to such an extent that long-term degradation would result. Secondly, the steel would conduct heat readily from the wind turbine structure above ground to the permafrost below. Therefore, even if insulation were

placed at the ground surface, ground temperatures could rise and result in thawing of the permafrost.

5.4 Timber Grillage

The timber grillage shown on Drawing 187-0601-F5 acts in the same manner as the steel grillage to resist the applied loads. Some steel members are included at the top to ease the load transfer from the wind turbine to timber members.

Unless kept permanently below the water table, the timber must be pressure treated for durability. As a result, it will have to be transported a similar distance as the steel components.

Timber can be used in permafrost areas. However, as for the steel grillage, the large depth of excavation required can cause long-term degradation of the permafrost. Therefore, it is recommended to provide appropriate insulation when the timber grillage is used in such cases.

The grillage design shown on Drawing 187-0601-F5 is a preliminary design for a wind turbine foundation constructed with timbet. It is designed for 100 kPa soil, with water table below grillage. The design can be modified to suit other soil conditions.

5.5 Piles

Driven piles have been ruled out due to non-availability of the specialized equipment required. If drilling equipment is available, however, piles could be drilled and set. With drilling equipment, screw anchors could also be installed. The primary advantage of piles and screw anchors is that they permit transfer of loads through poor material, such as muskeg or the active layer above permafrost, down to better bearing material below. As screw anchors are more efficient than piles in unfrozen soil, designs were produced using 300 mm diameter drilled-in pipe piles in permafrost, and screw anchors in unfrozen soil.

One potential problem with piles in permafrost is the risk of adfreezing, resulting in uplift forces in the active zone. To avoid this, sufficient insulation must be placed near the surface to permit the permafrost table to rise and reduce the active layer to 0.5 m maximum.

Piles should be placed in late winter or early spring when ground temperatures are at their coldest. To install the piles, a 400 to 500 mm diameter hole is drilled and cleaned out. The pipe pile is placed in the hole, and the space around the pile is backfilled with a soil slurry. The adfreezing of the slurry to the pile and to the drilled hole wall provides the strength for vertical loads. The process of backfilling with a slurry mix will cause the ground temperature to rise slightly. Care should be taken to ensure that the backfilling operation does not cause a significant rise in the ground temperature which could deteriorate the permafrost.

Both a concrete and a steel frame cap have been designed to carry the wind turbine loads to the piles. These pile foundation designs are presented on Drawings 187-0601-F6 and F7.

5.6 Screw Anchors

Screw anchors are similar to piles in that they can be used to transfer loads through poor material to better bearing material below. They are suitable for use in all soils except permafrost or extremely hard soil. They are particularly convenient for use in soils with a high water table where excavation would be difficult. Since their capacities can be made equivalent to those of piles, they have been specified as a substitute for the piles when the wind turbines are to be founded on unfrozen soil rather than permafrost. Screw anchor designs are shown on Drawings 187-0601-F6 and F7.

The installation of screw anchors is fast and can be done using a properly fitted standard backhoe. The steel frame or concrete caps can be erected immediately after the anchors are in place.

Screw anchors exhibit some movement before they develop their ultimate load capacity, however this movement can be reduced if the anchors are preloaded prior to erecting the wind turbine.

Screw anchors are shorter and lighter than piles and therefore present less shipping and handling problems. Corrosion is not a problem since they are manufactured already galvanized. They do not have as much lateral force capacity as piles, but by installing them at a small angle to the vertical plane they will adequately resist both vertical and horizontal loads.

5.7 Rock Anchors

Where sound rock is at or near the surface, it is best to anchor the footing into it to provide the necessary overturning resistance. The rock anchors specified are the type with an expanding shoe at the base. If a layer of weathered rock exists at the surface, it should be excavated and the foundation placed on sound rock, or the rock anchor may be taken to a greater depth to ensure adequate capacity against uplift.

Both a concrete cap and a steel frame have been designed to support the wind turbine on sound rock, and are presented on Drawings 187-0601-F8 and F9.

5.8 Ring Beam

A ring beam foundation basically consists of either a concrete or a steel frame, which is supported on foundation walls, which in turn are on strip footings. The strip footings engage the soil to resist uplift.

Due to the high overturning loads from the wind turbine, and the small area of soil engaged by the strip footings relative to a concrete mat, it was found that the ring beam would have to be fairly deep in order to develop the required overturning resistance, even in good, dry soil. The deeper excavation increases the chances of going below the water table.

As shallow concrete footings are more suitable for the soil types on which ring beam foundations could be used, the design of the ring beam foundation was not further pursued.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions Regarding Foundation Designs

A number of foundation designs have been presented in Section 5. Table 1 summarizes the soil conditions for which each of the designs are applicable.

From the discussion in Section 5, the following conclusions can be made.

1) The shallow concrete footing is applicable for a wide range of soil conditions and is relatively easy to construct, provided the concrete aggregate is available.

2) The steel and timber grillages can be used under a fairly wide range of soil conditions. They require considerable quantities of imported materials and are labour intensive to install.

3) The pile foundation is best suited for locations where permafrost is present, whereas screw anchors can be used in soils in which permafrost or rock are not present. Both the pile and screw anchor foundations can be used with concrete or steel frame caps.

4) Rock anchors with a concrete or steel frame cap are appropriate when rock is at or near the surface.

5) The shallow concrete footing is more appropriate than the ring beam in similar soil conditions.

6) The need for insulation has to be assessed for each individual site in conjunction with the selection of type of footing.

6.2 Recommendations

It is recommended that for unfrozen cohesive or granular soils the shallow concrete footing, screw anchor foundation and grillages be considered, in that order. The same applies where these soils are covered by a shallow layer of muskeg.

Where permafrost exists at a site, drilled frozen-in piles are the first choice, followed by shallow concrete footing and timber grillage.

In weathered rock the choice depends largely on the degree of weathering. In severely weathered rock which can be readily excavated, a shallow concrete footing is to be considered first as the most appropriate choice. However, grillages are also possible with appropriate modifications to suit site conditions.

In sound or slightly weathered rock the rock anchors are the most logical choice, with the depth of rock anchors adjusted according to condition of rock.

In all cases, the choice from feasible alternatives will depend on economical considerations related to each individual site, such as availability of local materials, equipment and labour, and the cost of transportation. It is recommended that the economics of the presented designs be undertaken as the next stage of this study.

Futhermore, it is recommended that the base of the wind turbine be redesigned to be symmetrical. This would simplify the connection of the structure to a steel frame type foundation.

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TABLE I

SOIL/FOUNDATION TYPES

Foundation Type / Soil Type	Shallow Concrete Footing	Steel Grillage	Timber Grillage	Piles (frozen-in)	Screw Anchors	Rock Anchors
Weak Cohesive	F1	F4	F5		F6 F7	
Stiff Cohesive	F2 F3	F4	F5		F6 F7	
Granular	F2 F3	F4	F5		F6 F7	
Weathered Rock	F3	Possible	Possible			F8 F9
Sound Rock						F8 F9
Permafrost	Possible		Possible	F6 F7		
Muskeg	Possible with soil replacement	Possible with soil replacement	Possible with soil replacement	F6 or F7 with permafrost below	F6 or F7 with unfrozen firm soil below	

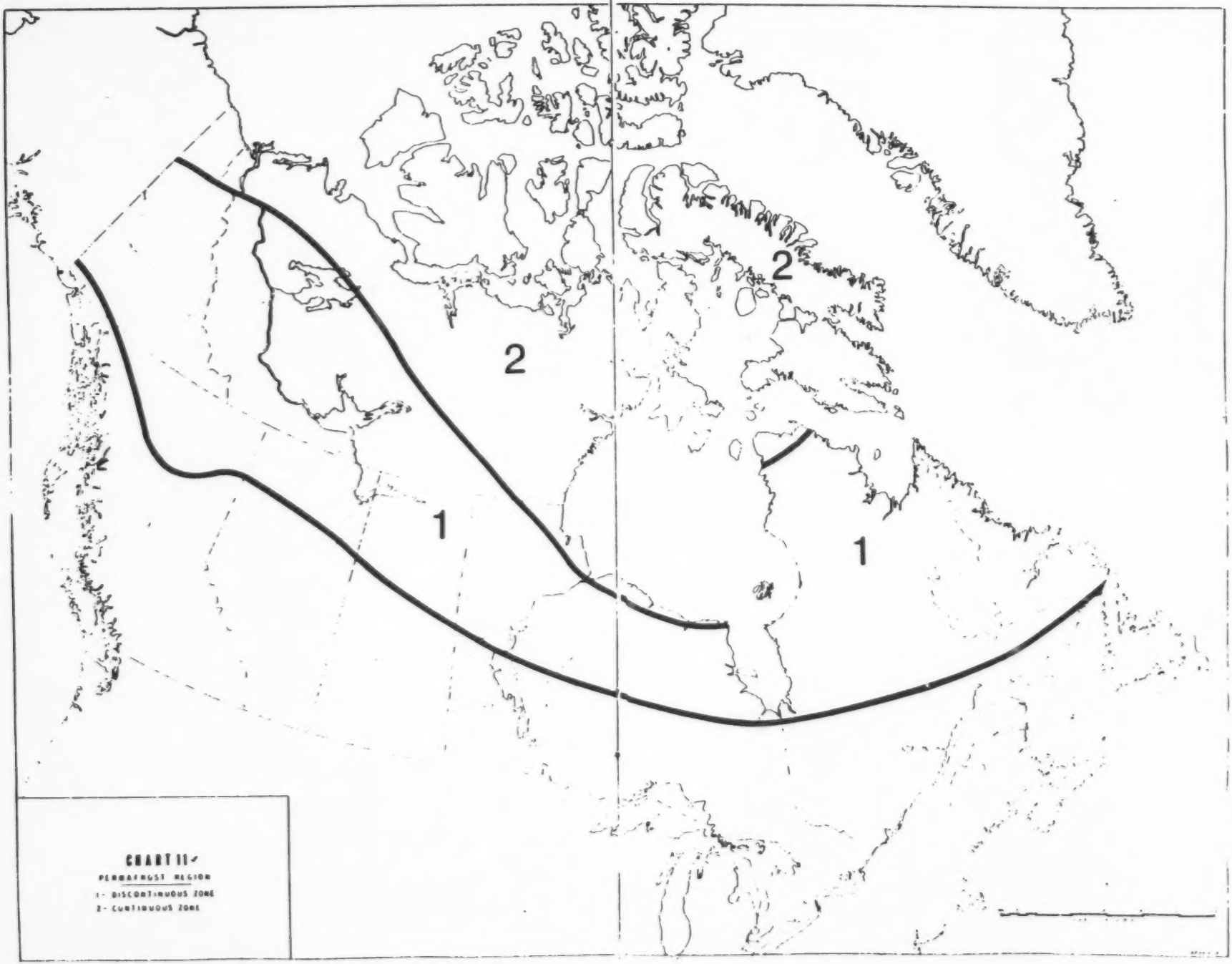
Table indicates Drawing Nos. of applicable typical foundation designs. The designs have to be modified where the soil conditions assumed for the typical designs are not met.

APPENDIX A

Howden HWP60 Wind Turbine

APPENDIX B

Regions in Canada


2
2
1
1
CHART II
PERMAFROST REGION
1- DISCONTINUOUS ZONE
2- CONTINUOUS ZONE

APPENDIX C

Foundation Designs

GENERAL NOTES

1. ALL EXCAVATIONS SHALL BE KEPT DRY, BY PUMPING IF NECESSARY, BEFORE POURING CONCRETE AND SHALL BE KEPT DRY UNTIL BACKFILLING IS IN PLACE.

2. BACKFILL SHALL BE PLACED SO AS TO PREVENT THE ACCUMULATION OF WATER AROUND FOUNDATIONS.

3. THE SOILS CONSULTANT SHALL CHECK THAT THE SOIL HAS THE REQUIRED SAFE BEARING CAPACITY.

4. THE SOILS CONSULTANT SHALL ESTABLISH REQUIREMENTS FOR INSULATION BELOW AND AROUND THE FOOTING.

5. ALL CONCRETE CONSTRUCTION SHALL CONFORM TO CSA STANDARD A-23.

6. CONCRETE SHALL HAVE A MINIMUM COMPRESSIVE STRENGTH AT 28 DAYS OR NOT LESS THAN 20 MPa.

7. REINFORCING STEEL SHALL BE DEFORMED BARS WITH A MINIMUM YIELD STRENGTH OF 400 MPa AND SHALL HAVE A MINIMUM CONCRETE COVER OF 75 mm.

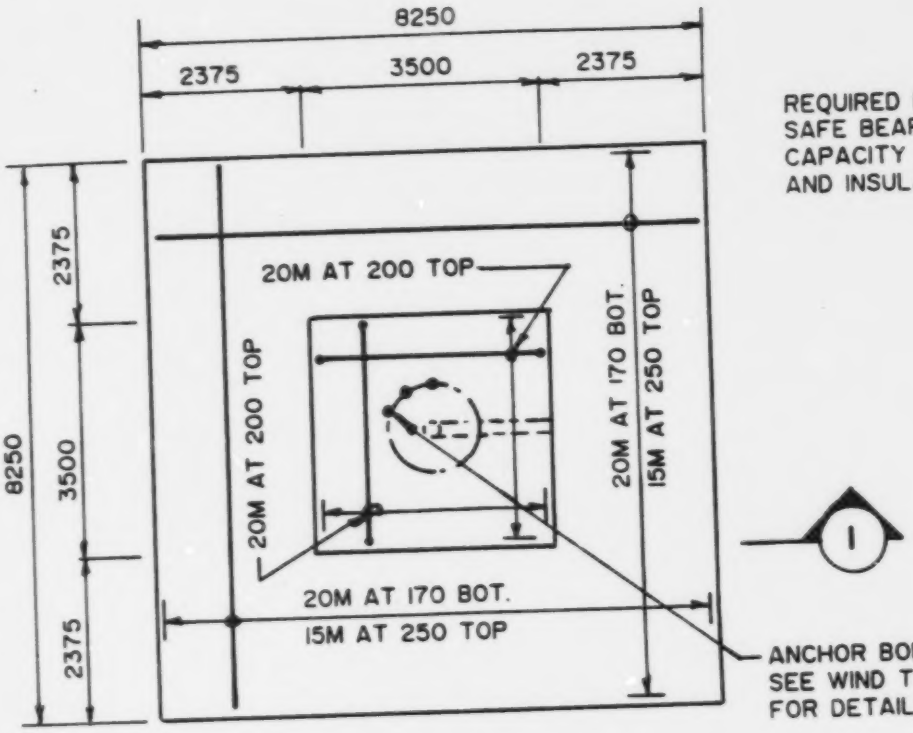
8. ALL STRUCTURAL STEEL IS TO BE NEW AND CONFORM TO CSA STANDARD G40.21M-300W UNLESS NOTED.

9. STRUCTURAL STEEL FABRICATION AND ERECTION SHALL CONFORM TO CSA STANDARD S16.1-M84.

10. WELDING SHALL CONFORM TO CSA STANDARD W59 AND SHALL BE UNDERTAKEN BY A FABRICATOR APPROVED BY THE CANADIAN WELDING BUREAU IN KEEPING WITH CSA STANDARD W47.

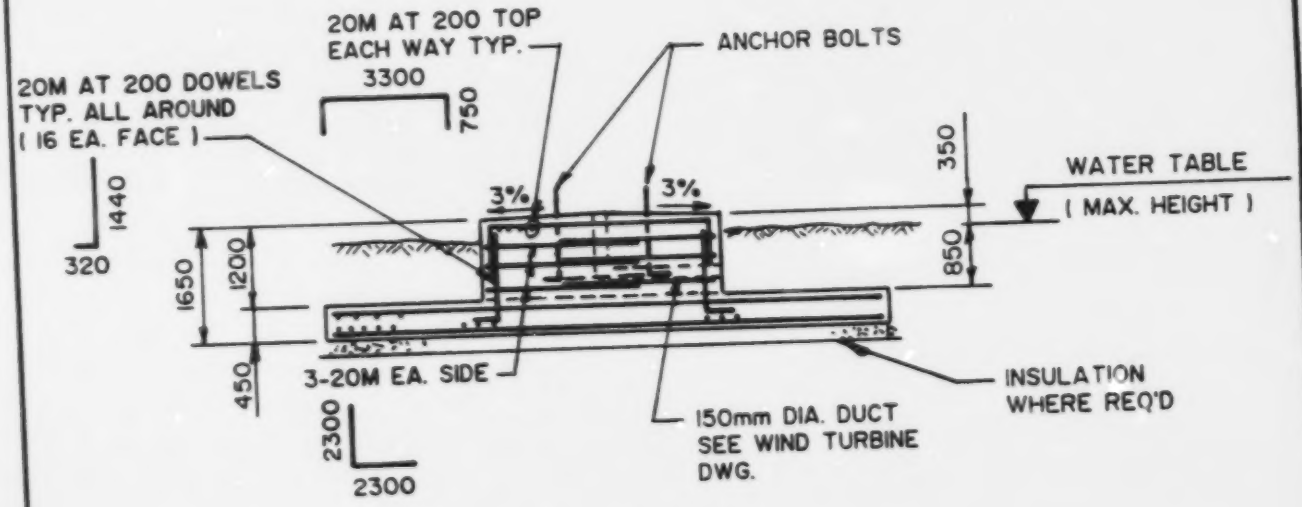
11. ALL STEEL MEMBERS (INCLUDING BOLTS) SHALL BE HOT-DIP GALVANIZED IN ACCORDANCE WITH CSA STANDARD G164.

12. FILL SPACE BELOW THE WIND TURBINE BASE PLATE WITH GROUT. GROUT SHALL BE THE NON-SHRINK TYPE, "IN-PAKT" OR AN APPROVED EQUAL INSTALLED AS PER MANUFACTURER'S INSTRUCTIONS.



FOUNDATION PLAN

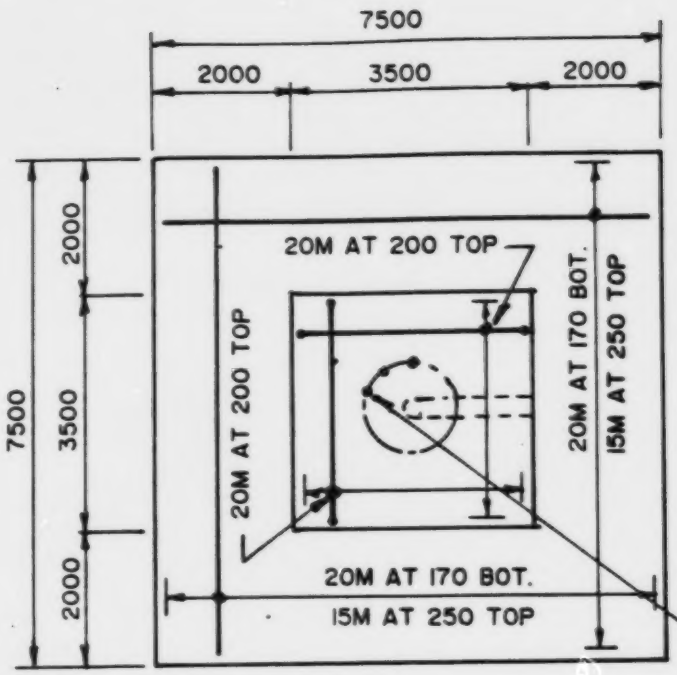
1 : 100



SECTION 1

1 : 100

Manitoba Hydro-Electric Board Consulting Engineers	DESIGNED: M.A.M.
	DRAWN: J.C.
SHALLOW CONCRETE FOOTING 50 kPa SOIL	PROJ. ENG.: A.T.
	APPROVED:
	DRAWING NO.: 187-0601-F1
SCALE: 1 : 100	DATE: APRIL. 1987

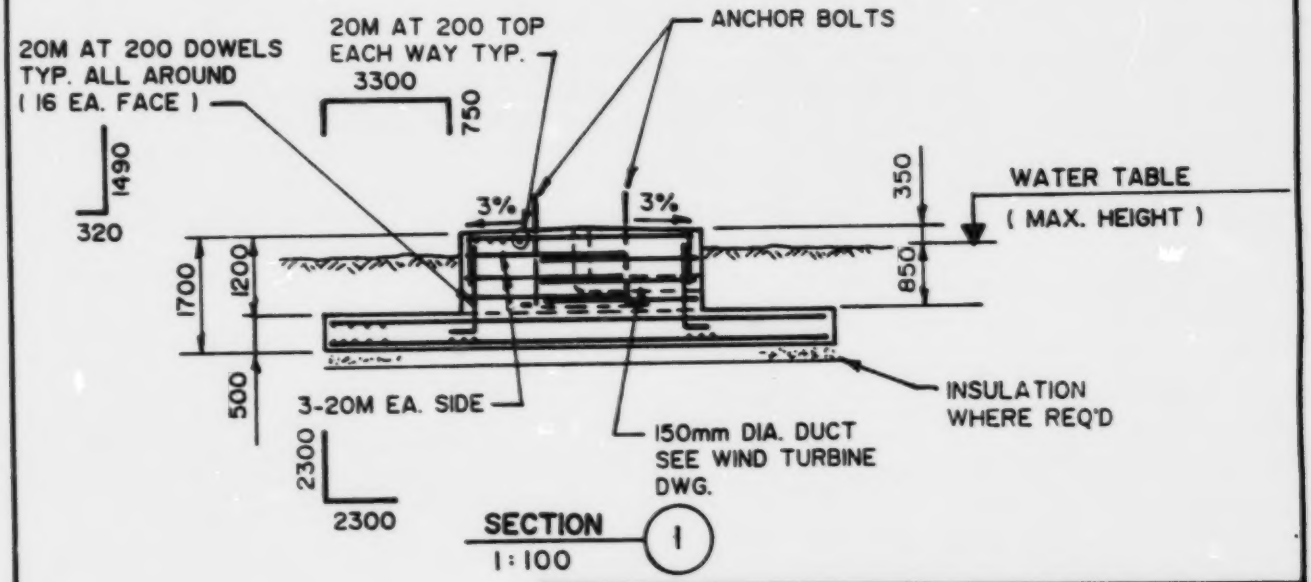


REQUIRED MINIMUM SAFE BEARING CAPACITY OF SOIL AND INSULATION - 100 kPa.

1

ANCHOR BOLTS 1330 BCD. SEE WIND TURBINE DRAWING FOR DETAILS.

FOUNDATION PLAN
1:100



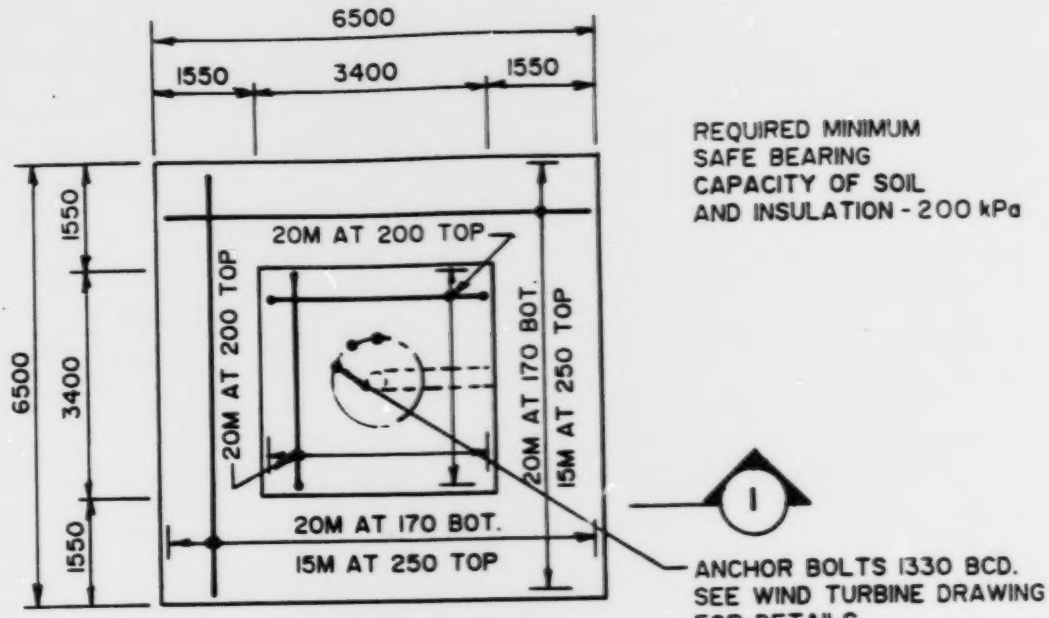
SECTION 1
1:100

Morrison Hershfield Limited
Consulting Engineers

DESIGNED:	M.A.M.
DRAWN:	J.C.
PROJ. ENG.:	A.T.
APPROVED:	
DRAWING NO.:	187-0601-F2

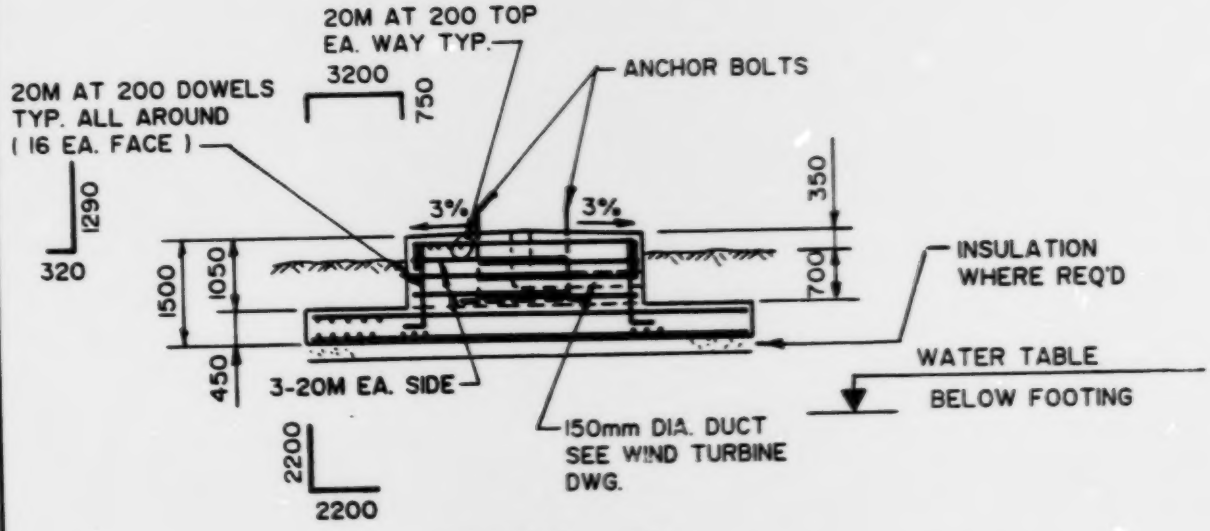
SHALLOW CONCRETE FOOTING 100kPa SOIL

SCALE: 1 : 100 DATE: APRIL. 1987.



FOUNDATION PLAN

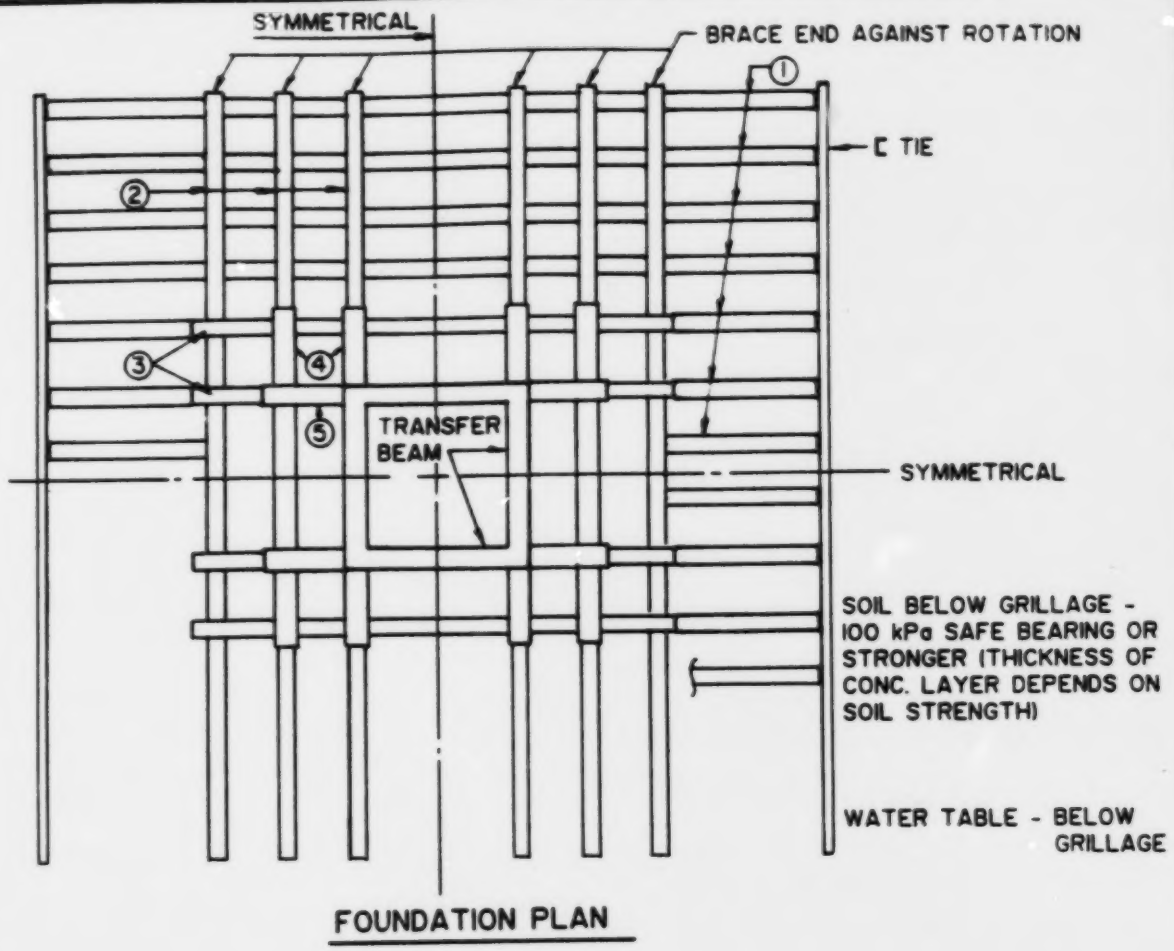
1 : 100



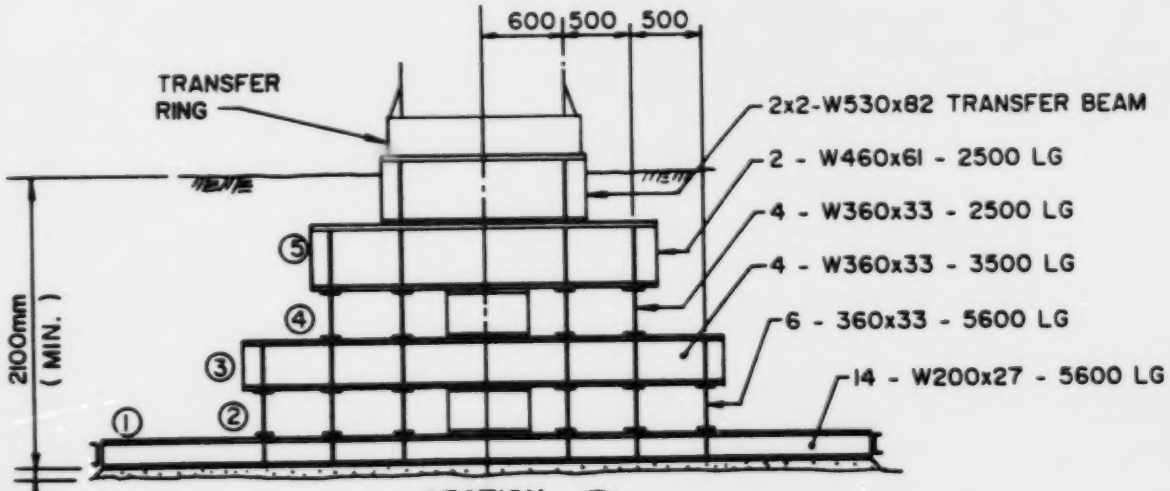
SECTION 1

1 : 100

Morrison Hershfield Limited Consulting Engineers	DESIGNED: M.A.M.
	DRAWN: J.C.
SHALLOW CONCRETE FOOTING 200kPa SOIL	PROJ. ENG.: A.T.
	APPROVED:
	DRAWING NO.: 187-0601-F3
SCALE: 1 : 100	DATE: APRIL. 1987



FOUNDATION PLAN



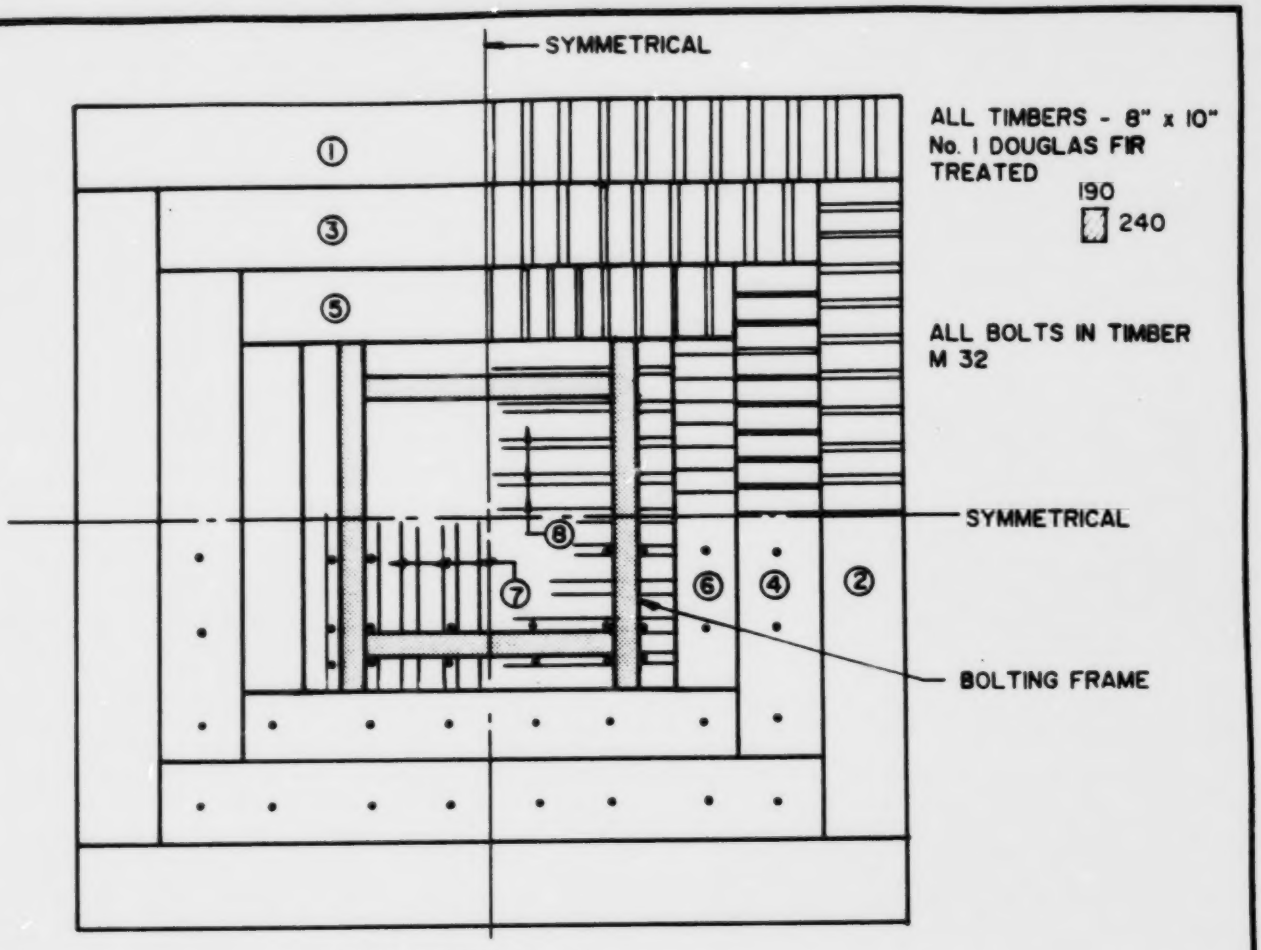
SECTION ①

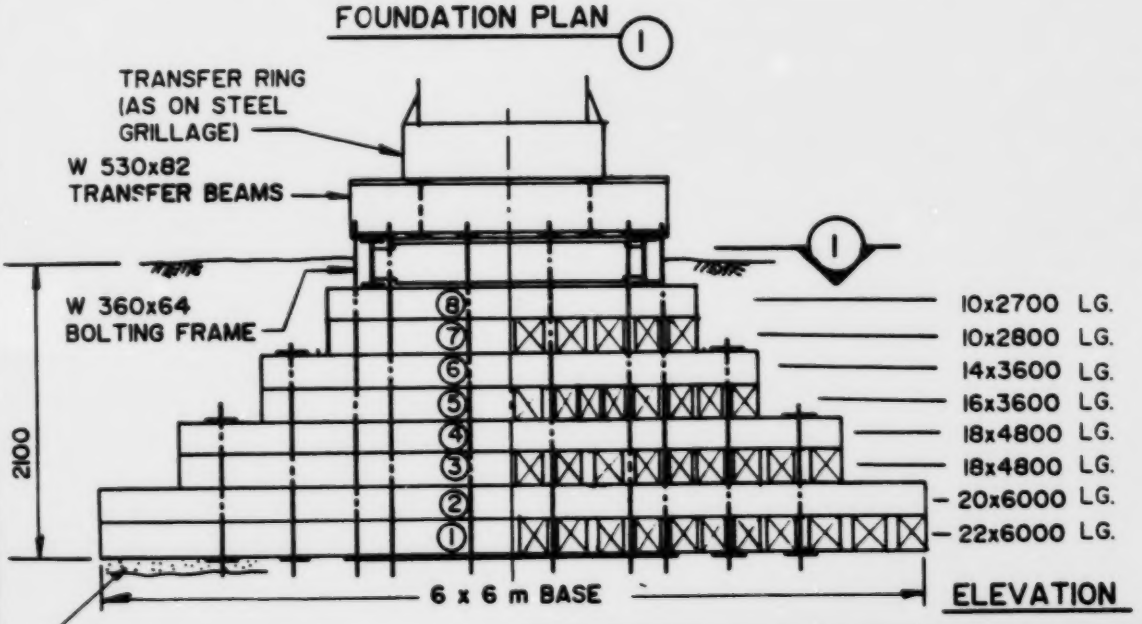
CONC. LAYER BELOW BEAMS : -
MIN. THICKNESS -
- 65 FOR 100 kPa SOIL
- 40 FOR 200 kPa SOIL (NOMINAL)

Manitoba Hydro-Electric Board Limited
Consulting Engineers

STEEL GRILLAGE FOUNDATION ON 100 kPa SOIL

DESIGNED:	M.A.M.
DRAWN:	S.L.
PROJ. ENG.:	A.T.
APPROVED:	
DRAWING NO.:	187-0601-F4
SCALE:	1:50
DATE:	APRIL, 1987.





40 CONCRETE LAYER
OR SMOOTH COMPACTED
SOIL.

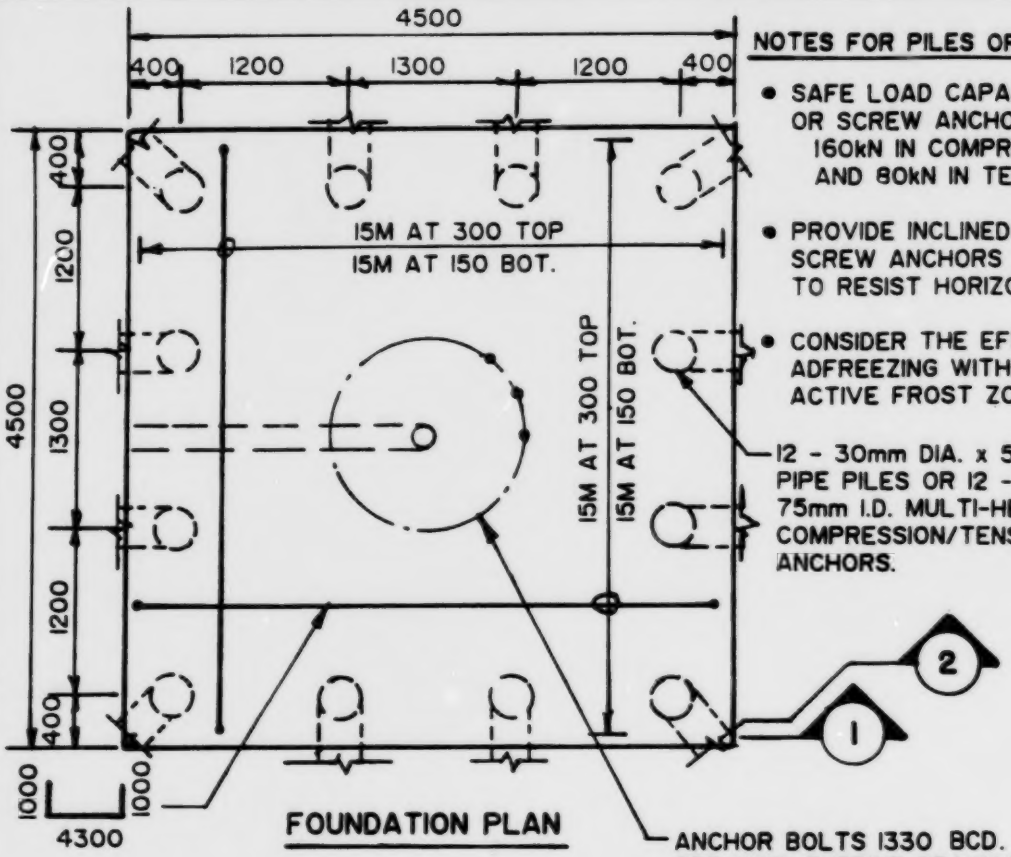
SOIL - 100 kPa SAFE BEARING.

WATER TABLE BELOW GRILLAGE

Morrison Hershfield Limited
Consulting Engineers

TIMBER GRILLAGE FOUNDATION ON 100 kPa SOIL

DESIGNED:	A.T.
DRAWN:	S.L.
PROJ. ENG.:	A.T.
APPROVED:	
DRAWING NO.:	187-0601-F5
SCALE:	1:50
DATE:	APRIL, 1987



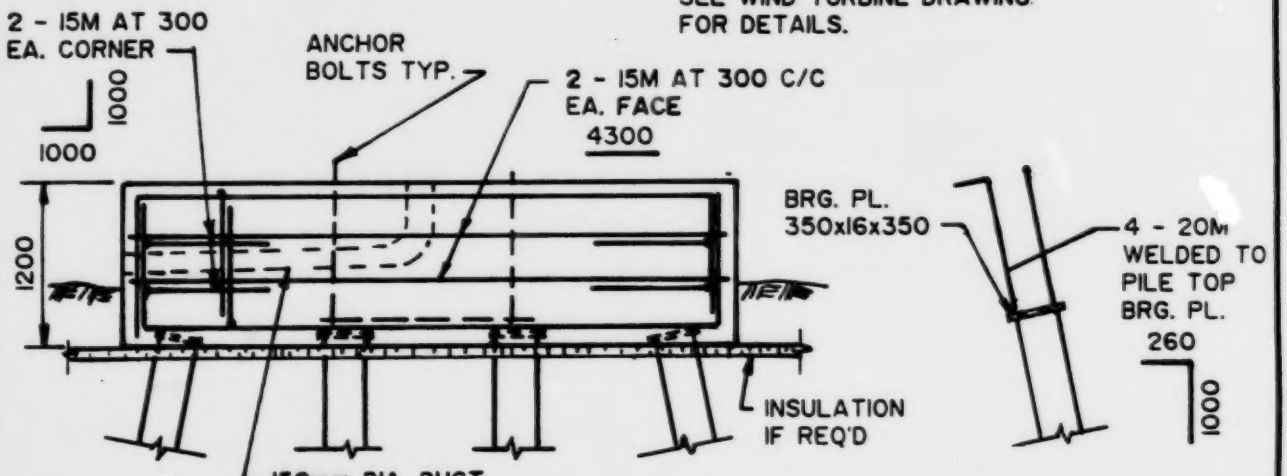
FOUNDATION PLAN

NOTES FOR PILES OR SCREW ANCHORS

- SAFE LOAD CAPACITY OF ONE PILE OR SCREW ANCHOR: 160kN IN COMPRESSION AND 80kN IN TENSION.
- PROVIDE INCLINED PILES OR SCREW ANCHORS AS REQ'D. TO RESIST HORIZONTAL LOADS.
- CONSIDER THE EFFECT OF ADFREEZING WITHIN THE ACTIVE FROST ZONE.

12 - 30mm DIA. x 5mm THICK PIPE PILES OR 12 - INCLINED HS-II 75mm I.D. MULTI-HELIX COMPRESSION/TENSION SCREW ANCHORS.

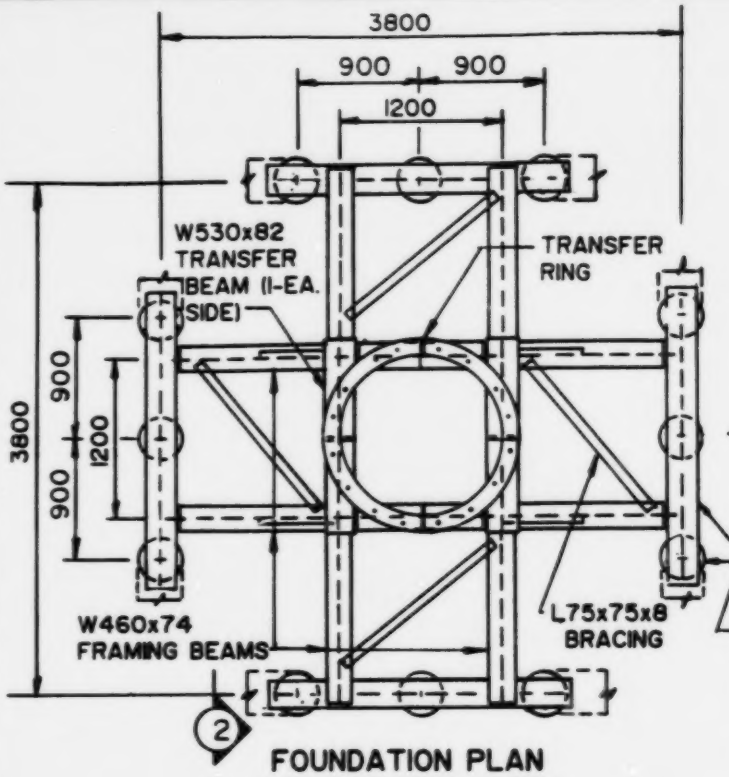
ANCHOR BOLTS 1330 BCD. SEE WIND TURBINE DRAWING FOR DETAILS.



SECTION 1

SECTION 2

Manitoba Hydro-Electric Board Limited Consulting Engineers MH	DESIGNED: M.A.M.
	DRAWN: J.C.
PILE/SCREW ANCHOR FOUNDATION WITH CONCRETE CAP	PROJ. ENG.: A.T.
	APPROVED:
	DRAWING NO.: 187-0601-F6
SCALE: 1 : 50	DATE: APRIL. 1987.



FOUNDATION PLAN

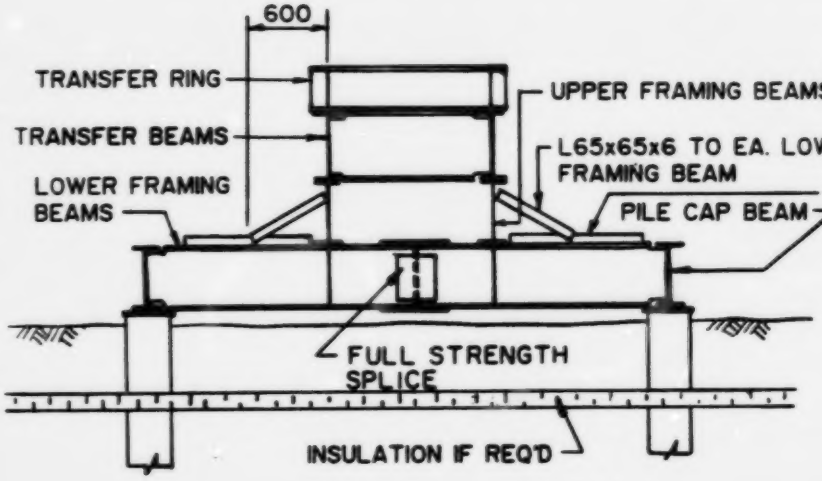
NOTES FOR PILES OR SCREW ANCHORS:

- SAFE LOAD CAPACITY OF ONE PILE OR SCREW ANCHOR:
  160 kN IN COMPRESSION
  AND IN TENSION
- PROVIDE INCLINED PILES OR SCREW ANCHORS AS REQ'D TO RESIST HORIZONTAL LOADS.
- CONSIDER THE EFFECT OF ADFREEZING WITHIN THE ACTIVE FROST ZONE

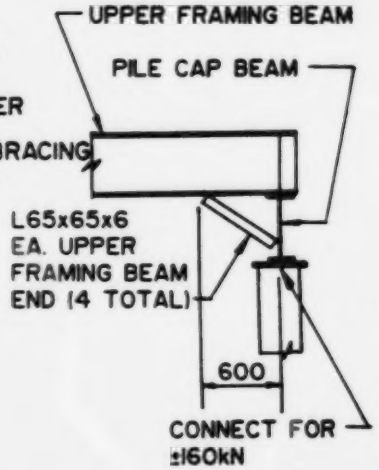
1

W460x74x2200mm LG PILE CAP BEAM

12-300mm ϕ x 5mm THICK PIPE PILE OR 12 - INCLINED HS-II 75mm I.D. MULTI-HELIX COMPRESSION/TENSION SCREW ANCHORS.

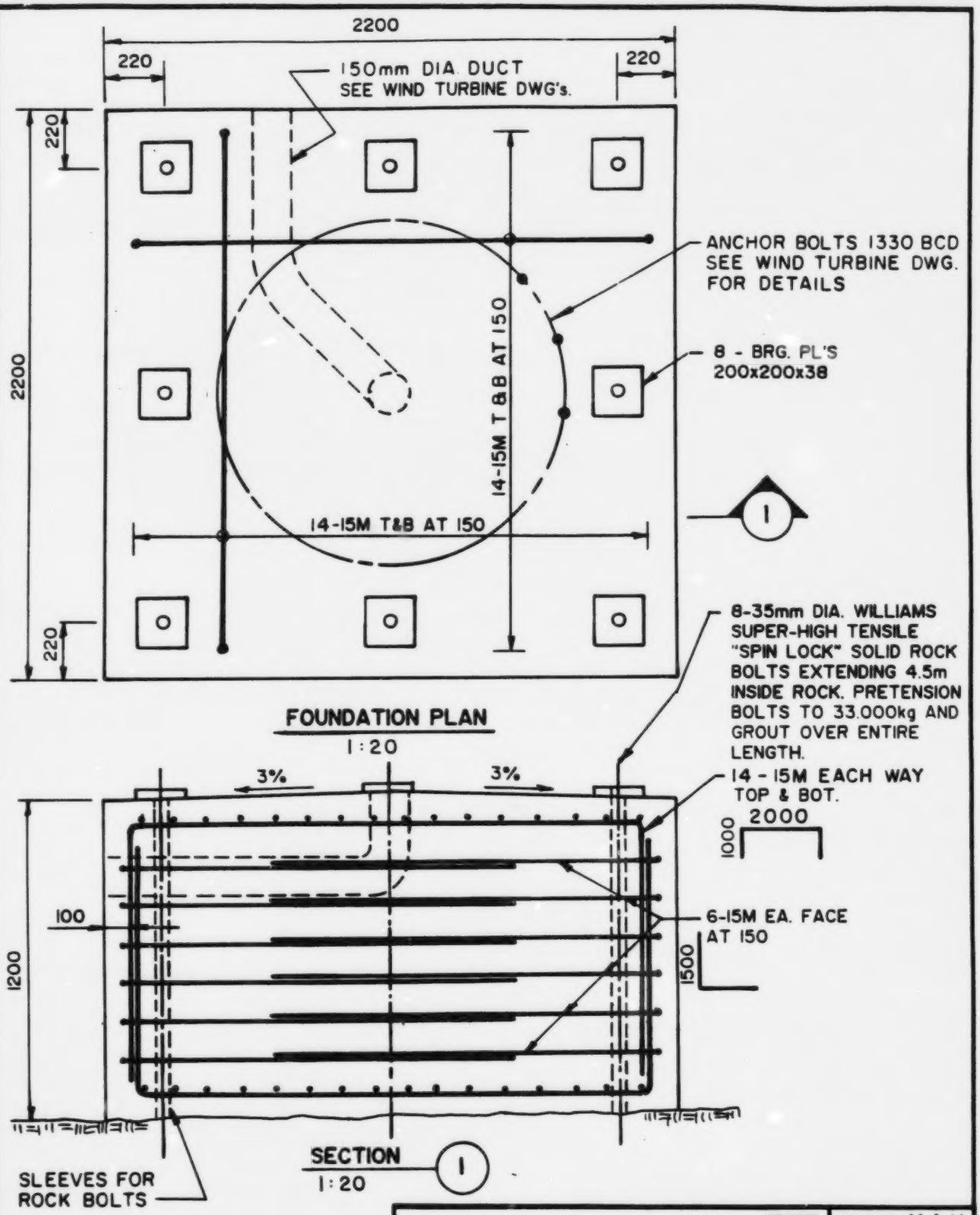


SECTION 1



SECTION 2

Morrison Hershfield Limited, Consulting Engineers	DESIGNED: M.A.M.
	DRAWN: S.L.
PILE/SCREW ANCHOR FOUNDATION WITH STEEL FRAME CAP	PROJ. ENG.: A.T.
	APPROVED:
	DRAWING NO.: 187-0601-F7
SCALE: 1 : 50	DATE: APRIL. 1987

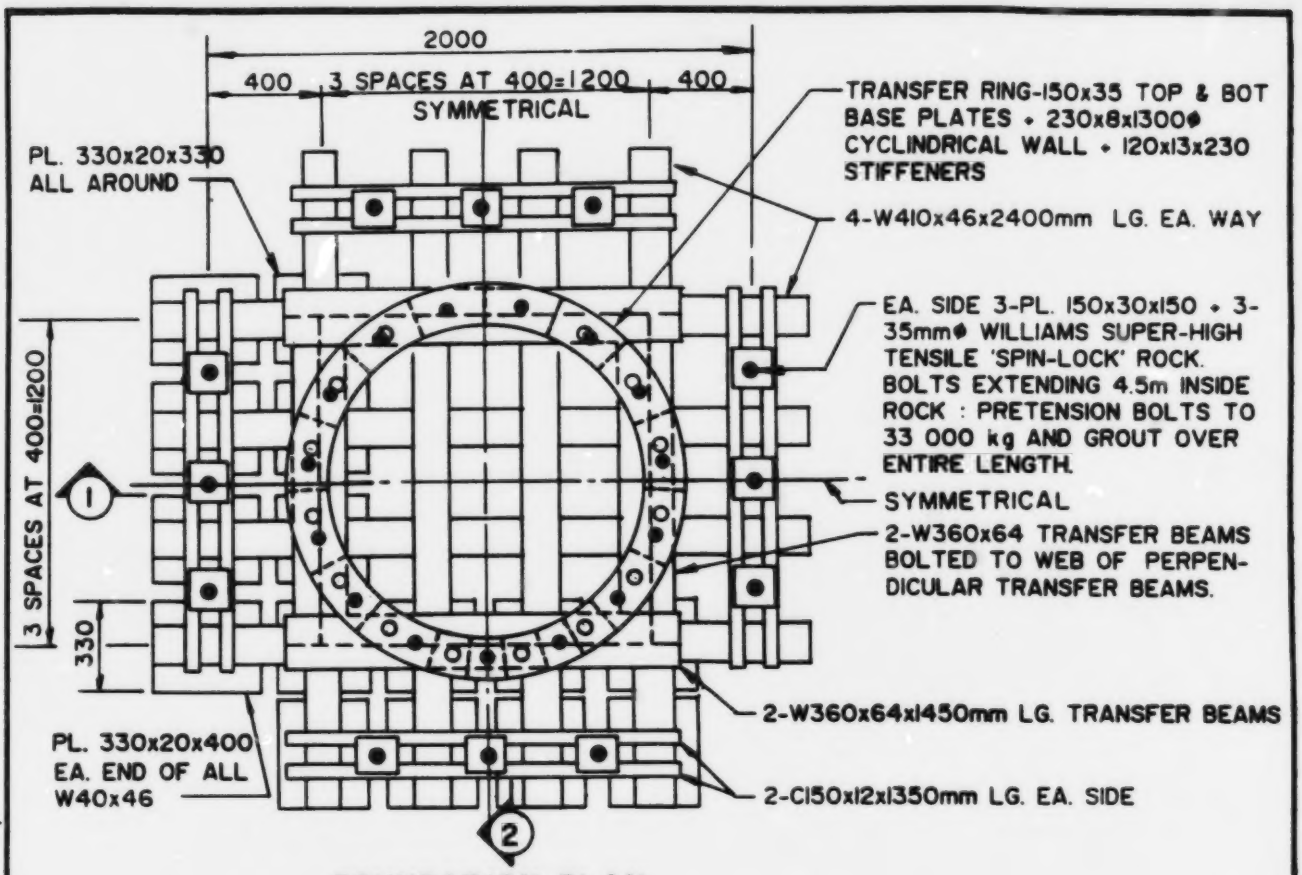


REQUIRED MINIMUM SAFE BEARING CAPACITY - 1000 kPa

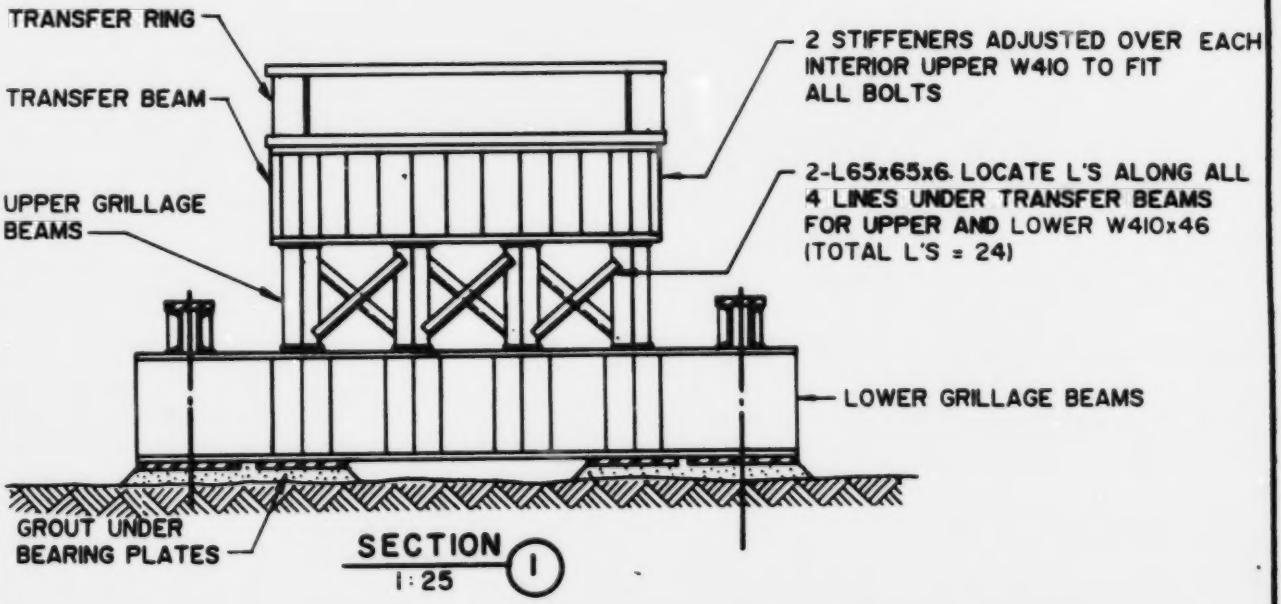
Manitoba Hydro-Electric Board Limited
Consulting Engineers

CONCRETE FOOTING
ON SOUND ROCK

DESIGNED:	M.A.M.
DRAWN:	S.L.
PROJ. ENG.:	A.T.
APPROVED:	
DRAWING NO.:	187-0601-F8
SCALE:	1:20
DATE:	APRIL, 1987


2000
400
3 SPACES AT 400=1200
400
SYMMETRICAL
PL. 330x20x330 ALL AROUND
TRANSFER RING-150x35 TOP & BOT BASE PLATES + 230x8x1300ϕ CYCLINDRICAL WALL + 120x13x230 STIFFENERS
4-W410x46x2400mm LG. EA. WAY
EA. SIDE 3-PL. 150x30x150 + 3-35mmϕ WILLIAMS SUPER-HIGH TENSILE 'SPIN-LOCK' ROCK. BOLTS EXTENDING 4.5m INSIDE ROCK : PRETENSION BOLTS TO 33 000 kg AND GROUT OVER ENTIRE LENGTH.
SYMMETRICAL
2-W360x64 TRANSFER BEAMS BOLTED TO WEB OF PERPENDICULAR TRANSFER BEAMS.
3 SPACES AT 400=1200
330
1
2-W360x64x1450mm LG. TRANSFER BEAMS
PL. 330x20x400 EA. END OF ALL W40x46
2-C150x12x1350mm LG. EA. SIDE
2

FOUNDATION PLAN
1:25


TRANSFER RING
TRANSFER BEAM
UPPER GRILLAGE BEAMS
2 STIFFENERS ADJUSTED OVER EACH INTERIOR UPPER W410 TO FIT ALL BOLTS
2-L65x65x6. LOCATE L'S ALONG ALL 4 LINES UNDER TRANSFER BEAMS FOR UPPER AND LOWER W410x46 (TOTAL L'S = 24)
LOWER GRILLAGE BEAMS
GROUT UNDER BEARING PLATES

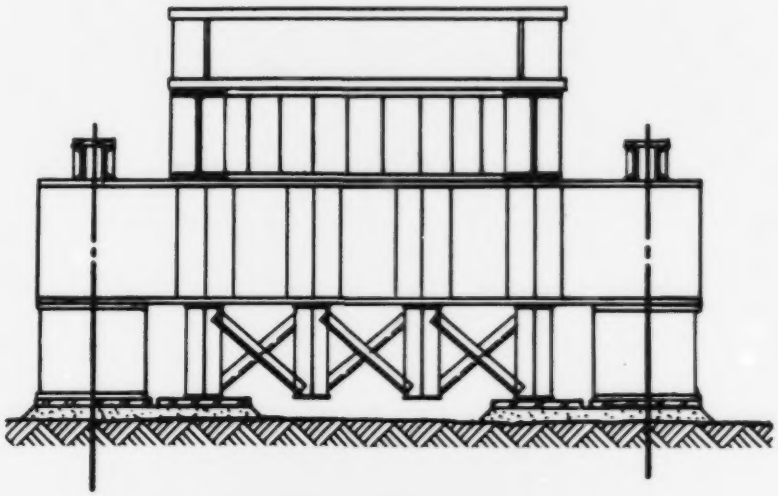
SECTION 1
1:25

REQUIRED MINIMUM SAFE BEARING CAPACITY - 1000kPa

Morrison Hershfield Limited
Consulting Engineers

STEEL GRILLAGE FOUNDATION ON SOUND ROCK - PAGE 1

DESIGNED:	M.A.M.
DRAWN:	S.L.
PROJ. ENG.:	A.T.
APPROVED:	
DRAWING NO.:	187-0601-F9A
SCALE:	1:25
DATE:	APRIL, 1987



REQUIRED MINIMUM SAFE BEARING CAPACITY - 1 000 kPa

SECTION (2)
1:25

Morrison Hershfield Limited Consulting Engineers MH		DESIGNED: M.A.M.
		DRAWN: S.L.
STEEL GRILLAGE FOUNDATION ON SOUND ROCK - PAGE 2		PROJ. ENG.: A.T.
		APPROVED:
		DRAWING NO.: 187-0601-F98
SCALE: 1:25	DATE: APRIL, 1987	

ADDENDUM TO REPORT NO. 18706011 June 16/87

Prelim Cost Estimates -

for an accessible

South Ontario Site:

	Drawing *	Estimate $
Shallow conc footing 50 kPa soil	F1	25,000
Shallow conc footing 100 kPa soil	F2	23,000
Shallow conc footing 200 kPa soil	F3	20,000
Steel grillage foundation 100 kPa soil	F4	30,000
Timber grillage foundation 100 kPa soil	F5	36,000
Pile/screw anchor foundation with concrete cap (10 m piles)	F6	27,000
Pile/screw anchor foundation with steel frame cap (10 m piles)	F7	29,000
Concrete footing on sound rock	F8	18,000
Steel grillage foundation on sound rock	F9	23,000

* Ref - Report No 18706011